APPENDIX A

List of Participants

Attendees at the workshop on Techniques for Modeling Human Performance in Synthetic Environments, presented at the University of Nottingham on March 17, 1999, and their affiliations at that time.

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APPENDIX B

Description of Soar and ACT-R

Soar and ACT-R are two of the most commonly used cognitive architectures. They can be seen as theories of cognition realized as sets of principles and constraints on cognitive processing, a cognitive architecture (Newell, 1990). They both provide a conceptual framework for creating models of how people perform tasks. They are thus similar to other unified theories in psychology, such as PSI and COGENT.

Both Soar and ACT-R are supported by a computer program that realizes those theories of cognition. There are debates as to whether and how the theory is different from the computer program, but it is fair to say that they are at least highly related. It is generally acknowledged that the program implements the theory and there are commitments in the program that must be made to create a running system that are not in the theory—places where the current theory does not say one thing or another.

As cognitive architectures, their designers intend them to model the full breadth and width of human behavior. Such cognitive architectures, including the ones discussed in this report, do so to a greater or lesser extent, usually with the areas covered increasing monotonically over time. This approach to modeling human cognition is explained in books by Newell (1990) and Anderson (Anderson, 1993; Anderson & Lebiere, 1998). These books also provide introductions of Soar and ACT-R.

Further information on both Soar and ACT-R are available from the references cited here, as well as the sources included in the bibliography at the end of this appendix. The sources in the bibliography were used to write this appendix, particularly Johnson (1997), Jones (1996a, 1996b), and Ritter (2001).

B.1 Background of Soar and ACT-R

Soar and ACT-R are each based on a set of different theoretical assumptions, reflecting, largely, their different conceptual origins. Soar was developed by combining three main elements: (1) the heuristic search approach of knowledge-lean and difficult tasks, (2) the procedural view of routine problem solving, and (3) a symbolic theory of bottom-up learning designed to produce the power law of learning (Laird, Rosenbloom, & Newell, 1986). However, many of the constraints on Soar's theoretical assumptions consist of general characteristics of intelligent agents, rather than detailed behavioral phenomena. Soar's outlook is more biased towards performance because it arose out of an AI-based tradition.

In contrast, ACT-R grew out of detailed phenomena from memory, learning, and problem solving (Anderson, 1983, 1990; Singley & Anderson, 1989). ACT-R is thus suited more for predicting slightly lower-level phenomena, and is slightly more suited for predicting reaction times more accurately, particularly for tasks under 10 seconds in duration. These differences are relative; both architectures have been used for both highand low-level models, with attention paid to both performance and time predictions. ACT-R's outlook is more biased towards predicting reaction-time means and distributions because it arose out of a more experimental psychology tradition.

B.2 Similarities Between Soar and ACT-R

Soar and ACT-R can be seen as similar in numerous ways. They both have two kinds of memory, declarative (facts) and procedural (rules), although they represent these items differently. Typical instantiations of them now have input provided through a model of perception and output buffered through a model of motor behavior (Byrne, 2001; Chong, 2001; Ritter et al., 2000).

Both Soar and ACT-R model behavior by reducing much of human behavior to problem solving. Soar does this rather explicitly, being based upon Newell's information processing theory of problem solving (Newell, 1968), whereas ACT-R merely implies it by being goal-directed.

In both architectures these memories are conceptually infinite, with no provision being made for the removal of any memory item in ACT-R (the Soar architecture does perform removal of declarative memory, which therefore can be seen as a type of short-term memory). Manipulation of declarative memory can be accomplished by adding new items or changing existing ones. For procedural memory, rules may only be added to both architectures.

The course of processing involves moving from an initial state to a specified goal state. ACT-R has only one possible goal state (Version 5), whereas Soar may have several of them arranged in a stack. Movement between the initial and goal states usually involves the creation of sub-goals to accomplish the various parts leading up to the satisfaction of the goal.

Both ACT-R and Soar maintain a goal hierarchy where each subsequent sub-goal becomes the focus of the system. In ACT-R, these must be satisfied in a serial manner and in the reverse of the order they appear in the hierarchy (which is not directly visible to both the model and the modeler). Soar generally proceeds in a serial way as well, but is capable of removing (or solving) intermediate sub-goals should the current problem solving resolve a sub-goal that is much higher in the goal hierarchy. This difference makes ACT-R potentially less reactive, although work is in progress to make ACT-R more reactive (Lebiere, 2001).

B.3 Differences Between Soar and ACT-R

There are also fundamental differences between the two architectures. Soar only moves between states through changing the state as part of a decision procedure, which rules can vote on but cannot directly cause. In Soar, when no more productions can fire, an operator is selected or a state is modified. This whole process is called a decision cycle. Where an operator cannot be selected (e.g., due to preferences for the set of operators conflicting each other or not being complete), a sub-goal is created with a goal to choose the next operator. Movement between states is done in ACT-R by firing productions, which may change the state and goal stack directly.

Soar allows multiple rules to fire in parallel. This may lead to impasses because the knowledge in the rules may suggest different operators, but problem solving is available to resolve this. In ACT-R, when the conditions of several productions are met, a conflict resolution mechanism selects the production that it estimates to have the highest gain.

Learning in Soar occurs only for production memory. New rules are created by the architecture whenever a sub-goal is resolved, such that when next encountering the same situation, the new production fires without the need to enter a new sub-goal. This type of information can include which operator to select, or how to implement an operator. These rules tend to be atomic, and in nearly all cases can be seen as immediately fully learned. This learning mechanism (chunking) can implement a wide range of learning effects, including long-term declarative memory learning—for long-term declarative information is represented solely as the result of procedural memory.

ACT-R learning involves both declarative and procedural memory. When rules fire they become stronger, and as declarative memories are used more they are strengthened as well. Each production also has an expected gain value based on its probability of success and its cost and the current goal's value. The expected gain is used for conflict resolution; the production with the highest expected gain is selected when several productions are possible matches. The more often the production meets with later success (e.g., the sub-goal ends up being solved), the higher this probability for the rule will become. This strength also influences the activation of the declarative memory items that are matched by the condition of the production, and also the rule execution time.

Each item in declarative memory has an associated activation that changes based upon how often it has been used, and how strongly it is associated with other items that are being used. The more often an item is used, the higher its base level activation will become. The more strongly associated an item is with ones that are being used, the more chance that item has for having its activation raised.

A rule learning mechanism is less often used in ACT-R models, and when it has been used, the resulting rules are typically created in a nascent state such that they have to be created several times before they are fully learned.

B.4 Bibliography for Soar and ACT-R

ai.eecs.umich.edu/soar/, the Soar Group's homepage

act.psy.cmu.edu/, the ACT-R Group's homepage

acs.ist.psu.edu/soar-faq, Soar Frequently Asked Questions list

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Glossary of Acronyms and Abbreviations

ABC	A* search with Bounded Costs
ACT-R	Adaptive Control of Thought - Rational
ACT-R/PM	A perceptual-motor component added to ACT-R
AI	Artificial Intelligence
AMBR	Agent-Based Modeling and Behavior Representation project
APEX	A tool for applied human performance modeling developed at NASA
API	Application Programing Interface
ATAL workshops	Architectures, Theories, And Languages Workshop series
BDI architectures	Architectures based on representing Beliefs, Desires, and Intentions
CES	Cognitive Environment Simulation
CHIRP	Confidential Human Factors Incident Reporting Program
CHREST	Chunk Hierarchy and REtrieval STructures
CMAC	Cerebellar Model Arithmetic Computer
CoCoM	Contextual Control Model
COSIMO	COgnitive SIMulation MOdel
CREAM	Cognitive Reliability and Error Analysis Method
DERA	Defence Evaluation and Research Agency (UK)
DCOM	Distributed COmponent Model
DIS	Distributed Interactive Simulation (system)
EPAM	Elementary Perceiver and Memoriser
EPIC	A cognitive architecture based on a production rule interpreter that assumes no cognitive limitations on processing and a set of perceptual motor processors that provide a limitation on cognition.
FLAME	Fuzzy Logic Adaptive Model of Emotions
GAs	Genetic Algorithms

HCI	Human-Computer Interaction
HLA	Higher-Level Architecture
IDM	Individual Data Modeling, modeling based on fitting the behavior of individuals and then aggregating the results, as compared with fitting data aggregated across subjects.
IMPS	Internet-based Multi-agent Problem Solving
JACK	JAVA Agent Compiler and Kernel
JAVA	A procedural language used to support web applications
JFC	JAVA Foundation Classes
JNDI	JAVA Naming and Directory Interface
KBS	Knowledge-Based Systems
LTM	Long-Term Memory
MLP	Multi-Layer Perceptron
ModSAF	Modular Semi-Automated Forces
NDM	Naturalistic Decision Making
ONR	Office of Naval Research
RDM	Rapid Decision Making
RMI	Remote Method Invocation
SDM	Sparse Distributed Memory
SEs	Synthetic Environments
SMOC	Simplified Model Of Cognition
SRG	System Response Generator
STM	Short-Term Memory
UTC	Unified Theory of Cognition

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Major terms are flush left. Minor or subterms are indented, duplicate terms in italics.